Chapter 3

Agricultural Inputs and Their Energy Costs 1900–2010

The socio-metabolic transition to industrial society led to displacing agriculture as the main source of energy and materials and generalizing the use of fossil fuels and minerals (Krausmann and Haberl 2002; Fischer-Kowalski and Haberl 2007; Krausmann et al. 2008; Kuskova et al. 2008; Infante-Amate et al. 2015). This transition also affected the agricultural sector itself, which underwent big quantitative and qualitative changes in its technical means of production. These technological changes are usually associated with corresponding increases in agricultural production (increase in land productivity) and in the reduction of human labor (increase labor productivity) (Boserup 1981; Giampietro et al. 1999; Fischer-Kowalski et al. 2014). As we have seen in Chap. 2, Spanish agroecosystems experienced significant intensification and productive specialization. Given that land uses were segregated, that many connections between them broke down, and technological innovation orientations (Fernández Prieto 2001), agroecosystems increasingly needed inputs imported from outside the agricultural sector. Organic inputs produced in the farms themselves and in the local environment, such as manure and animal traction, were replaced by large quantities of inorganic inputs powered and manufactured with fossil fuels, including synthetic fertilizers and pesticides, machinery, fuel and electricity (Guzmán Casado and González de Molina 2009).

In this chapter, we quantify the inputs used in Spanish agriculture since the beginning of the twentieth century. The aim is to examine the evolution of the social fund element, i.e., the technical means of production (TMP), during the industrialization process. TMP eventually not only had a decisive role in maintaining productive activity but productive activity ended up being dependent on it. The objective is not that of examining technical changes in agriculture, which goes beyond the scope of this research, but to evaluate the magnitude of the changes and their consequences for the functioning of Agrarian metabolism (AM). Although we have been expressing flows in tons of materials, in this chapter, we chose to express them in units of energy to give a fuller account of the developments. In Chap. 6, where we analyze the structure and functioning of agrarian metabolism by relating both the funds and the flows from which they originate, we will express inputs in tons to maintain metric consistency.

3.1 Comments on Methodology

According to our methodological proposal, inputs from outside the agricultural sector constitute the Imports (I) in the MEFA methodology. These Imports added to Domestic Extraction (DE) determine domestic consumption (DC) after deduction of Exports (E). Although we considered both, human work and animal traction, to calculate the EROIs, they are not taken into account here because they can be defined as flows that circulate within the agroecosystem and do not, therefore, come from outside. We thus developed a time series on the use of external inputs from 1900 to 2008. Their type and quantity were obtained mainly from agricultural statistics supplemented with technical reports as well as research studies and were based on the assumption that growth rates were constant during the years for which we lacked data. Yearbook data included fertilizers since 1933, tractors and other agricultural machines since 1955, fuels since 1960, pesticides since 1933 and greenhouses and tunnels from 1975 onwards. Pesticide data from 1950 to 1980 were expressed in monetary terms, and we converted them into weights using deflation data from Carreras and Tafunell (2005). Fertilizers in 1900–1922 were estimated from the data compiled by Gallego Martínez (1986) and Mateu Tortosa (2013). Fuel consumption data for 1950 and 1990–2008 were retrieved from Spanish statistics (MI 1961a, b; MINETUR 2015) and from FAOSTAT (FAO 2016) for the years 1970–1980. Fuel consumption from 1900 to 1940 was estimated based on the machinery's installed capacity. Electricity consumption data for 1950 were obtained from the INE (1960), from Carpintero and Naredo (2006) for 1960, from FAOSTAT (FAO 2016) for 1970–1980 and from MINETUR (2015) for 1990 onwards. The consumption of electricity before 1950 was estimated assuming that agricultural electricity represented the same proportion of total electricity consumption in Spain as in 1950. Corominas data (2010) was used to take into account upstream electricity consumption in the irrigation. The surface areas represented by each type of irrigation were taken from MAGRAMA (2015a). The official machinery data in the first half of the twentieth century was complemented by data from Martínez-Ruiz (2000). We considered that 97% of the greenhouses belonged to the “‘Almería vineyard’ ‘type and 3% were of the’ ‘Glass greenhouse’” type (MAGRAMA 2008).

The data are presented at selected decadal intervals, that is, 1900, 1910, 1922, 1933, 1940, 1950, 1960, 1970, 1980, 1990, 2000, and 2008, as we did for biomass production. Where possible, the decennial values were defined based on 5-year averages. The series combines raw data taken directly from historical sources, estimates made by other researchers and our own estimates. Since official statistics are published annually, we show long-term trends for some years as we believe they are of interest. We divided the inputs into industrial (chemical fertilizers, machinery, etc.) and non-industrial (biomass) inputs. The energy we calculated for industrial inputs is embodied energy, that is, the sum of gross energy of the input plus the energy needed for its production and distribution. The embodied energy of industrial inputs evolved over time, following varying trends in production energy efficiency and the delivery of inputs. We developed a working document that describes the embod-

ied energy (and its components) in agricultural inputs over the 1900–2010 period, together with theoretical and methodological considerations (Aguilera et al. 2015). Given that the data in this working document are provided in a 10-year format and do not always correspond to data for Spain, missing data were estimated by linear interpolation. To estimate the machinery's embodied energy, we took into account the installed power (MW) of the machinery, the years of manufacture of the “mix” of machinery and the actual replacement rate in the year studied (estimated according to records and annual census). Estimated embodied energy in the electricity was based on the Spanish electric mix and thermal power plant efficiency (Bartolomé-Rodríguez 2007; UNESA 2005; MINETUR 2016; REE 2012), supplemented with data on the embodied energy of fuels, taken from Aguilera et al. (2015). In terms of non-industrial inputs, the energy contained in the net imported biomass (seeds and feeds) was the gross energy of the different products, calculated using conversion factors included in Guzmán et al. (2014). The energy cost of transport taken from Aguilera et al. was added to it (2015). The energy required to produce the biomass was not taken into consideration, to avoid double accounting problems, since this cost must be attributed to the agroecosystems of origin.

The embodied energy metric would be equivalent to the concept of “cumulative energy demand” used in life cycle assessments as well as to the concept of “energy intensity” used in some energy studies. All embodied energy components are expressed in terms of gross energy. Energy requirements refer to the energy used in the production of a given input. They are divided into direct and indirect energy requirements. The direct energy requirements refer to the gross energy of the fuels used directly in the production process. Indirect energy requirements include all the remaining processes necessary for input production and its use on the farm, including the production and transport of fuel, production, and transport of raw materials, energy integrated into buildings and equipment and transportation of finished products to the farm. Worthy of note, only physical processes were included. For the analysis of the agricultural systems' energy inputs, we considered it more appropriate to use gross energy (GE), rather than net energy, since the former reflects total energy contained in the input. In addition, agricultural energy products were almost always expressed in gross energy values, as in our review of the energy content of biomass products and residues (Guzmán et al. 2014). Therefore, we also used GE values in our analysis of the embodied energy of agricultural inputs. On the other hand, we did not apply any quality correction factor to the calorific value of the different fuels.

Changes in energy efficiency in the manufacturing and operation of inputs were taken into account, especially industrial ones. To our knowledge, however, these changes in efficiency have barely been considered in historical analyses of agrarian systems. Only studies based on monetary data systematically take these changes into account (e.g., Cleveland 1995; Cao et al. 2010). The studies by Pelletier et al. (2014) on egg production in the USA and Pellegrini and Fernandez (2018) on global energy use in agriculture are two of the few examples of studies accounting for temporary changes in the energy efficiency of agricultural inputs from a life cycle analysis perspective.

The general trend has consisted in significant technological improvements in energy efficiency in the production of most agricultural inputs, such as nitrogen and phosphate fertilizers, steel for the production of machinery, etc. (Smil 1999, 2013; Jenssen and Kongshaug 2003; Ramirez and Worrell 2006; Dahmus 2014). Over some periods, such as during the 1980s energy crisis, this trend intensified due to the increase in energy prices and concerns about the security of energy supplies (Bhat et al. 1994). However, some agricultural inputs, which in the beginning required little energy due to the ease of extraction, have ended up demanding higher consumption levels for their extraction and refining (Meadows et al. 1972; Gutowski et al. 2013). Despite technological improvements, the energy efficiency of raw material production may have decreased. This is the case, for example, of oil and gas production in the USA (Hall et al. 2009, 2014), and generally worldwide (Gagnon et al. 2009; Hall et al. 2014), where energy return on investment (EROI) is already decreasing. An exhaustive historical compilation of embodied energy coefficients has been carried out for the main agricultural inputs (Aguilera et al. 2015). The calculations described in this chapter are based on this latter compilation.

3.2 Mechanical Traction

In our categorization, traction includes the energy used to perform mechanical work contained in agricultural tasks, excluding the pumping of water for irrigation, and also excluding the work performed by draft animals, which is based on internal energy from the agroecosystem. Therefore, it includes the work accomplished by self-propelled machines in the field, such as tillage, sowing or harvesting, but also the tasks that were performed outside the farm, such as threshing. Quantifying the total energy and environmental impacts of mechanical traction requires determining the amount of fuels used for direct and indirect energy consumption as well as the embodied energy of manufacturing and machinery maintenance. Additional data on animal traction and greenhouse gas emissions from animal and mechanical traction is provided in Aguilera et al. (2019a).

3.2.1 *Machinery*

In this section, we reconstruct the time series of the most important parameters to estimate energy and environmental impacts associated to farm machinery production and maintenance in Spain. In our case, this means reconstructing, for each type of farm machine, the annual census, the number of annual registrations in the census and removals from it, the average useful life, and the weight of new, removed and average machines of the census. The machine types studied are locomobiles, threshers, tractors, harvesters, other motors (static), tillage machinery and other farm implements.

The number of motorized farm machines is reported yearly by official statistics since 1970 (MA 1973; MAPA 1997; MAGRAMA 2012), and each 5 years since 1955 (MA 1973), although Martinez-Ruiz (2000) provides an annual series since 1955. We also have machine numbers in 1932 (MAIC 1932) and 1947 (Martinez-Ruiz 2000). Martinez-Ruiz (2000) provides threshers and locomotive numbers in 1900. We assumed that the first tractors were registered in 1902 and the first self-powered harvesters and 1-axis tractors (rototillers) in 1940. We estimated values in the missing years assuming constant growth rates between the two closest years with available data. We also assumed that there was no growth during the Civil War period (1936–1939).

The number of machine registrations each year is provided since 1970 (MAPA 1997; MAGRAMA 2012). There is no available information regarding yearly removals of farm machinery from the census. Therefore, we estimated this value as the census of a given year minus the sum of registrations of that year plus the census of the previous year. We estimated registrations and removals in years previous to 1970 assuming the same removal rate, with respect to the census, as the average of the first 20 years with available data (1970–1989).

In some specific years, the census and the yearly registration values do not match, i.e., when the change in the census between 2 years is higher than reported registrations in that year. This means that registrations are too low even assuming that there were no removals in that year. In those cases, we have assumed that there were no removals, and the number of registrations was equaled to the difference between the census of the previous and the current year. Moreover, in 1980 there was an unusual peak in the census, followed by the continuation of a fairly stable trend. We corrected the census value in that year assuming that it followed a constant growth rate.

There is no information on the total number of harvesters registered each year, only on the number of cereal harvesters. Likewise, the number of total harvesters is reported in 1990 for the first time. We used the ratios of total harvesters to cereal harvesters from the census, in those years where data is available, to estimate the total number of harvesters registered (in the whole series) and censed (in years previous to 1990). Total harvesters represented 105% of cereal harvesters in 1990 and 115% in 2011. The ratio of 1990 was used for the pre-1990 series.

The census of “other engines” (excluding irrigation) is only available for a few years along the whole studied period: 1932 (MAIC 1932), 1962 (INE 1963), 1973 (MA 1973), 1980, 1985 and 1988–1993 (MAPA 1997). We assumed constant growth rates in the missing years. In 1900, we assumed the same number of other engines as threshers, in line with the proportion between these two types of machines in the 1932 census.

The number of threshers is provided in 1900, 1947, 1955–1975 (Martinez-Ruiz 2000), 1932 (MAIC 1932) and 1976–1981, 1983 and 1986 (INE 1997). We estimated the missing years assuming constant growth rates.

There is high uncertainty in the evolution in the number of machines during the first half of the twentieth century (Graph 3.1a). However, we can observe a substantial growth between 1900 and 1932. From 308 locomobiles, 300 threshers and 300 “other engines” at the beginning of the century, to 538 locomobiles, 5062 threshers, 5312

Graph 3.1 Historical evolution of the number of motorized machines in Spanish agriculture, 1900–1960 (a) and 1900–2008 (b), in thousands of units

“Other engines” and 4084 tractors in 1932. Despite the impact of the Civil War and the post-war period, by 1947 the number of tractors had doubled, and in 1955 there were 27,671 units. Thus, the data shows that locomobiles never grew too high above the levels of the nineteenth century, while most of the growth in farm machinery until almost 1930 was dominated by threshers and “other engines”, followed by tractors, which became dominant in the 1950s. The number of tractors and harvesters kept growing until the end of the period in 2010, up to 1,049,950 and 60,263, respectively (Graph 3.1b). As we will see later, this is not due to ever-increasing mechanization of Spanish agriculture but to the lack of removals from the census.

The number of registrations peaked in the late 1970s in the case of tractors and rototillers (Graph 3.2a and b, respectively), and in the late 1960s in the case of harvesters (Graph 3.2c). However, removals from the census never matched registrations, implying the continuation of the growth in census numbers (Graph 3.2c) even decades after the peak in annual registrations. This implies that the average age of registered farm machinery was also growing.

Graph 3.2 Historical evolution of the annual number of registrations and removals of tractors (a), rototillers (b) and harvesters (c) from the agricultural census, 1900–2008, in thousands of units per year (three-year moving average)

We estimated the average life expectancy of machinery assuming that the machines removed in a given year were the oldest ones in the census (Graph 3.1). In the period previous to 1970, when there were no registrations data, and thus the uncertainty of removals was very high, we assumed a constant life expectancy equal to the average of the first 20 years with available data (1970–1989). In the case of threshers, locomotives and other engines we do not have registrations and removals data during the whole studied period. In those cases, we assumed a constant life expectancy of 20 years.

Graph 3.3 shows a large increase in the estimated life expectancy of farm machinery in Spanish agriculture in the period (1970–2010). Some reports support this assumption showing that 31% of harvesters were more than 15 years old in 1990 (Pérez-Minguijón 1992), 55% of the tractors were more than 15 years old in 2006 (ANSEMAT 2006), and 47% of them were more than 20 years old in the same year (MAPA 2007). The age of the machines is typically inversely related to their yearly use time. Thus, harvesters less than 5 years old were used 38 days per year, while those older than 15 years were used 22 days per year on average in Spain in 1990 (Pérez-Minguijón 1992). Thus, the increase in apparent life expectancy does not necessarily mean that the machines are used for an increasingly longer period. Instead, the most probable cause is that old tractors with very little use or even not used anymore are not removed from the census (Pérez-Minguijón 1992, 1999). This possibility is supported by the fact that diesel fuel consumption has not grown significantly since the mid-1970s (Sect. 3.2.2), despite installed tractor power has quadrupled in the same period and specific fuel consumption of new tractors has only decreased by 33% in that period (Aguilera et al. 2015). Moreover, specific reports which have studied the real use of farm machines further support this argument. For example, a study by MAPA (2007) found that 14.5% of registered tractors were not being used. Thus, the overestimation of the census data implies an underestimation of removals and thus an increase in apparent life expectancy according to our calculations. (Graphs 3.4, 3.5 and 3.6).

Graph 3.3 Historical evolution of the life expectancy of tractors, rototillers, and harvesters, 1970–2010, in years

Graph 3.4 Historical evolution of the average rated power per machinery unit, 1900–2010, in HP/unit

3.2.2 Fuels

Direct energy consumed in traction includes all agriculture fuels reported by official agricultural statistics except those employed in irrigation and in modern livestock production (particularly for heating). We have estimated fuel energy employed in irrigation in Sect. 3.3. Regarding fuel consumption in livestock production, we have assumed that all non-liquid fuels, except coal during the first half of the twentieth century (which was used by threshers and locomobiles), were used in this activity. In the first part of this section, we show our reconstruction of total fuel consumption in Spanish agriculture. Then, we segregate traction, irrigation, and livestock fuel consumption.

The first official published data on fuel consumption in Spanish agriculture refers to 1950 and 1951 (MI 1961a, b). In 1978, the *Anuario de Estadística Agraria* report (MA 1978) included an annual series of fuel consumption in Spanish agriculture starting in 1958. Another series, also by MA, includes gasoline, diesel, and oil fuel consumption from 1960 to 1977 (MA 1966, 1970, 1975a, b, 1976, 1977). FAOSTAT also reports agricultural fuel consumption data in Spain, starting in 1970 (FAO 2016). The last official series is released by the Spanish Ministry of Industry and starts in 1990 (MINETUR 2015). On the other hand, scholars studying energy balances have also compiled historical sources to estimate fuel consumption in Spain. The first of these works, by Naredo and Campos (1980), reports fuel consumption data, distinguishing diesel fuel and other fuels, in 1950, 1951, 1977, and 1978. A more recent work (Carpintero and Naredo 2006) reports total fuel consumption from 1960 to 2000, based on OECD energy balances. The latter reference is also the source of FAOSTAT data.

The studies mentioned above employ different units for reporting fuel consumption, including kcal, toe (Mg oil equivalent), tce (Mg coal equivalents), liters, and joules. Moreover, some of them express the data as net energy and other as gross energy. We have attempted to harmonize the data expressing all of them as TJ gross

Graph 3.5 Historical evolution of the rated power of the average machines, registered machines and removed machines, including tractors (a), rototillers (b), harvesters, (c) and other engines (d), in HP/unit (three-year moving average)

Graph 3.5 (continued)

Graph 3.6 Historical evolution of the installed traction power in Spanish agriculture, 1900–2010. Total installed power, in GW (a) and gross annual registrations, in MW/year (b)

Table 3.1 Energy conversion units of fossil fuels

	Density	Litres/ton	GCV	NCV	GCV	NCV
	kg/m ³		GJ/t	GJ/t	GJ/litro	GJ/litro
Kerosene	802.6	1246	46.2	43.9	37.1	35.3
Motor gasoline	740.7	1350.1	47.1	44.8	34.9	33.1
Gas /dieseloil	843.9	1185	45.7	43.4	38.5	36.6
Naphta	690.6	1448	47.7	45.3	33	31.3
LPG	522.2	1915	50.1	46.2	26.2	24.1
Natural Gas	799.6	1250.6	50.4	45.4	40	36.3

Source IEA (2015)

energy. Energy conversion units employed are shown in Table 3.1. The results of the comparison are shown in Graph 3.7.

In Graph 3.7 we can observe varying levels of coincidence in reported fuel consumption in Spanish agriculture between the compared sources. Some of the differences might be explained by differences in energy conversion coefficients (between different units and net to gross energy). However, the differences between sources

Graph 3.7 Historical evolution of fuel consumption in Spanish agriculture according to different sources, 1950–201, in petajoules

are often not fixed, implying that there are other factors responsible for the observed differences. We constructed an own series (dotted line in Graph 3.7) prioritizing the national official sources, followed by international official sources. We completed the series in some periods with data of missing fuel types from secondary sources (research articles and monographs). We have tried to include the least number of conversions between energy units and types, and we have discarded the data not coherent with the other series. In particular, FAOSTAT (FAO 2016) data from 1970 to 1989 has been complemented with data from Spanish reports. Our series starts with 1951 and 1952 data from Naredo and Campos. Then, we assume a constant growth rate in fuel consumption until 1958, when data from MA (1978) starts. From 1970 to 1974 we take diesel and LPG data from FAOSTAT, but gasoline and other liquids data from MA (1978). From 1975 to 1979 we take all data from FAOSTAT, but estimate other liquids consumption by interpolating MA (1978) value in 1969 with FAOSTAT value in 1980. From 1980 to 1989, all values are from FAOSTAT. From 1990 to 2013, all values are from MINETUR (2015), the official Spanish statistics, which is very similar to FAOSTAT for most fuel types, although there are significant differences in some specific fuels types and periods, such as fuel oil from 1990 to 2003 (Graph 3.8). Moreover, FAO data does not include renewable fuels reported by

Graph 3.8 Comparison of FAO (2016) and MINETUR (2015) data of fuel consumption in Spanish agriculture, by type of fuel, 1990–2012 (FAO values expressed as % of MINETUR values)

Graph 3.9 Historical evolution of fuel consumption in Spanish agriculture, by fuel type, 1900–2008, in petajoules/year

MINETUR (2015), such as biomass and biogas, nor renewable thermal energy such as solar thermal and geothermal. In Graph 3.9, we show the selected annual series of fuel consumption from 1958 to 2012.

For constructing the full 1900–2008 decadal series, we had to estimate fuel consumption in the pre-1950 period. To our knowledge, there is a lack of published official statistics or estimations made by scholars on fuel consumption in Spanish agriculture before 1950. In our estimation, we assume that fuel consumption is proportional to the installed power of machinery, taking 1950–1951 data as a reference for fuel consumption. We distinguished the relative proportions of the different types of fuel based on qualitative information. For example, Naredo and Campos report that in 1948 diesel engines still represented only 20.6% of total installed capacity of agricultural machinery. According to Martínez-Ruiz (2000), 40% of the tractors still had petrol engines in 1955, and the majority of them in previous periods. We assumed that all new tractors from 1955 onwards used diesel fuel. This means that in 1960 gasoline would represent about 8% of fuel consumption in agriculture. This figure somewhat contradicts the annual data reported by MA (1978), which indicates that gasoline consumption from 1958 to 1961 was 0, while fuel oil represented 10–25% and diesel fuel 75–90%. In fact, null or almost null gasoline consumption values during the whole annual series from different sources in the 1958–2011 period also contradict the fact that many types of common agricultural small machines (such as chainsaws or weeding machines) employ gasoline. Therefore, we do not know whether gasoline amount is included within other types of fuel, or it is just not reported (the most probable).

This reveals two transitions in the major types of fuels used during the studied period, from coal to gasoline, during mainly the 1920s, and from gasoline to diesel, during the 1950s. It also shows the appearance in the last decades of gas products employed for heating, which significantly contributed to the increase in total fuel consumption in Spanish agriculture. The distinction between the different uses of fuels is shown in Graph 3.10.

Graph 3.10 Historical evolution of fuel consumption in Spanish agriculture in selected time steps, by activity type, 1900–2008, expressed as %. Own estimation (see text)

3.3 Irrigation

Irrigation inputs include infrastructure, on-farm energy use (energy consumption by water pumps), off-farm energy use (energy consumed in desalination and diversion channels) and indirect energy use (energy required for the production of fuels and electricity). Additional information on irrigation inputs and their C footprint is provided in Aguilera et al. (2019b).

In the last decades, starting with the “Tajo-Segura” water diversion in 1979 and continuing with other diversions and desalination projects in the last two decades, there has been an increase of high-energy consuming water sources (Graph 3.11).

Graph 3.11 Historical evolution of agricultural water use from unconventional sources, 1900–2008, in hm^3/year . Source Corominas (2010) and own estimations (see text)

Thus, all the increase in water availability for irrigation has implied higher energy requirements and environmental costs, a trend which is enhanced by the increase in the average depth of wells. There is a lack of data of average values of this factor at the national level in Spain, but regional data of Comunidad Valenciana in East Spain shows an increase from 23 to 87 meters between 1940 and 1970 (Calatayud and Martínez-Carrión 2005).

3.3.1 *Irrigation Systems*

We have estimated the surface area of each type of irrigation, including surface, sprinkle and trickle irrigation systems. The official statistics include an additional category named “intermittent irrigation” (“riego eventual”), which includes surface irrigation systems where water is only applied on certain occasions. This category has been equaled to one-third of surface irrigation systems for the estimation of the effectively irrigated surface area. Our estimation of the evolution of the surface area of each type of irrigation at the beginning of the twentieth century was based on two government reports (MAICOP 1904; MF 1918). We have used MAICOP (1904) data for our 1900 time-step, MF (1918) data for our 1922-time step and the average between the two of them for the 1910-time step. We have found no other data distinguishing each type of irrigation until the 1962 Agrarian Census (INE 1963). Thus, the values of the intermediate time steps (1933, 1940 and 1950) have been linearly interpolated. Up to 1960-time step, the only two irrigation categories were surface and intermittent surface irrigation. As we have data of total irrigation area for all time steps, we estimated intermittent surface irrigation values as explained above, while surface irrigation area values were calculated as the difference between total irrigation and intermittent irrigation. Sprinkle irrigation data for the 1960–1990 period was obtained from Calatayud and Martínez-Carrión (2005). We assumed that intermittent surface irrigation disappeared from 1970 onwards. Drip irrigation area data at the national level starts with 1989 data from Calatayud and Martínez-Carrión (2005). We used that value for our 1990-time step and assumed that drip irrigation area in 1980 was 1/10 of the area in 1989, based on the approximate growth rate of Murcia region from 1975 to 1992 (Calatayud and Martínez-Carrión 2005). Data for 2000-time step was taken from 2003 report by the Spanish Ministry of Agriculture (MAPA 2003), based on a 2002 survey. Data for 2008-time step was taken from 2015 report by the Spanish Ministry of Agriculture (MAGRAMA 2015a), based the average of 5 surveys performed from 2006 to 2010.

We can observe different stages in the evolution of irrigated area in Spain (Graph 3.12). During the beginning of the twentieth century, only surface irrigation systems existed. The majority of them, almost 0.89 million hectares (Mha), had constant irrigation, while 0.33 Mha were irrigated only intermittently. Thus, our corrected irrigated area series starts at just 1.00 Mha, and grows significantly until 1922 (1.24 million hectares). Then, the share of intermittent irrigation starts growing, making the corrected series to drop even if the sum of constant and intermittent

Graph 3.12 Historical evolution of irrigated area in Spain, 1900–2008, in hectares. Own estimation (see text)

surface irrigation areas still grows until 1940. The Autarky period (1940–1950) was associated to a reduction of both the gross and the corrected total irrigated area, the latter reaching 1.12 Mha. In 1950 starts a strong growth trend. The corrected irrigated area doubles in just 2 decades, and reaches 3.18 Mha in 1990. Growth continues until the present, although the growth rate has slowed down in the last decades. The first stage of the growth period was based on the expansion of constant surface irrigation area, while sprinkler irrigation expanded from 1960 to 1990 and trickle irrigation from 1980 onwards. In 1980, the surface irrigation area peaks at 2.30 Mha, and in the last time step it has dropped to half of this value (1.09 Mha), while trickle irrigation area reaches 1.54 Mha. This trend has continued until 2014, when surface irrigation dropped below 1 Mha and trickle irrigation covered 1.76 Mha.

3.3.2 Installed Mechanical Power

Data on the number of irrigation engines was gathered from different official publications, namely MF (1918) for 1916, MA (1933) for 1932, and MAPA (1980) for 1955–1980 (Graph 3.13). For the estimation of the number of irrigation engines in our selected time steps (Graph 3.14), we assumed a constant growth rate between 1900 and 1933, based on the observed growth rate between 1916 and 1932. For the period after 1980, in the case of combustion engines, we assumed the same growth rate as in the 1970–1980 period, while the number of electric engines was based on the evolution of electricity consumption in agriculture.

The number of installed engines (Graph 3.13) grew from about 1000 units in 1916 (JCA 1918) to 264,000 units in 1995 (MAPA 1997), reaching nearly 279,000 units in 2008. Most of the irrigation water in the early twentieth century was directly supplied by gravity from rivers, springs, and reservoirs through channels and *acequias*. Water

Graph 3.13 Historical evolution of the number of irrigation engines, 1900–2008, in thousands of units. Own estimation

Graph 3.14 Historical evolution of the average rated power of irrigation engines, 1900–2008, in KW/unit. Own estimation (see text)

elevation was only required in about 8 and 9% of the irrigated surface in 1904 and 1918, respectively (MAICOP 1904; MF 1918, respectively). In 1916, pump engines were used in about 31% of this surface requiring water elevation, while manual pumps (13,000 units) were used in 2% of this surface, water pumping windmills (3,000 units) in 3%, and water wheels (48,000 units) in 64% (MF, 1918). The number of water pumping windmills doubled up to 7000 units in 1932 (MAIC 1932), but there is no data on the continuation of the trend. The number of waterwheels had grown to 73,000 units in 1932 (MAIC 1932), and to 85,000 in 1962 (INE 1963), and there is no more data after that year.

There is information on the installed power of irrigation engines from 1955 to 1979 (MAPA 1980). The evolution of average engine power in the previous and later periods was estimated based on the evolution of the rated power of average traction

Graph 3.15 Historical evolution of the total installed power of irrigation engines, 1922–2008, in GW. Own estimation (see text)

machinery (see Sect. 2) (Graph 3.14). The total installed power of irrigation engines (Graph 3.15) was calculated by multiplying the number of engines by their average rated power.

The rated power of irrigation engines shows significant growth, more than doubling during the studied period (Graph 3.14). Most of the growth is observed during the 1950–1980 period when official statistics are available. These numbers are substantially lower than those of the Comunidad Valenciana region of Spain in the 1940–1970 period, where the average power of irrigation pumps was 21 KW/unit in 1940 (Calatayud and Martínez-Carrión 2005). But, according to the same source, the average power had grown up to 57 KW/unit in 1970, thus showing a similar growth pattern as in Spain as a whole.

The installed power for irrigation grew from 14 to 2496 MW in the 1922–2008 period (Graph 3.15). Electric engines represented around half of the installed power up to 1940, when heat engines started increasing their share up to nearly 90% in 1980. After that year trend reversed, and electric engines represented over 50% of the installed power in 2008.

3.3.3 Fuels

Fuel consumption in irrigation (Graph 3.16) was estimated based on the number of irrigation combustion engines, assuming a fixed fuel consumption rate per engine installed power of 7.0 GJ/KW, which is the consumption rate in 1995, the only year with available data on fuel consumption in irrigation (Corominas 2010). The distribution between coal and liquid fuels was based on the relative share of steam engines and internal combustion engines. In 1916 and 1932 the historical sources (respectively, MF 1918; MA 1933) provide specific data of engine fuel types. We

Graph 3.16 Historical evolution of direct fuel consumption in irrigation, 1900–2008, in petajoules. Own estimation (see text)

took the 1916 value for 1910 and 1922, and the 1932 value for 1933 and 1940. We assumed that the relative share of oil fuels in 1900 was half of that in 1916. Engines using coke oven gas, which were relatively common in the early twentieth century, have been included within the “oil” category. After 1950, we assumed steam engines to be phased out.

Total fuel consumption increased from 0.5 TJ in 1900 up to a peak 8450 TJ in 1990 and slowly declined after that year, reaching 7993 TJ in 2008. Coal dominates fuel consumption in the early twentieth century. Despite our estimation coal consumption remains practically flat from 1922 to 1940, its relative share drops dramatically from 1922 to 1932, due to the sharp increase in internal combustion engines.

3.3.4 Electricity

We found various sources reporting agriculture electricity use in different periods. The National Statistics Institute (INE) reports electricity consumption in agriculture from 1938 to 1958 (INE 1960), while another official study from the Industry Ministry (MI) provides a series from 1945 to 1959 (MI 1961a, b). The data in INE report is expressed as MWh, while the data in MI report is expressed as tons of coal equivalents (tce). If we express them as TJ, using the coefficient reported in MI document of 29.3 GJ/tce, we get much higher values from MI than for INE (Graph 3.9). However, the trends are identical from 1945 to 1955. On the other hand, INE data is similar to 1950 data reported by Naredo and Campos (1980), but show a drop in electricity consumption in 1956–1958 that is not supported by historical data, and which does not fit well with the following data series starting in 1960 (Carpintero and Naredo

2006). Thus, we made the exercise of recalculating MI values using a modified GJ/tce coefficient, equaling its data with those of INE (1960) in 1945. The results are shown in Graph 3.16. We can observe that the modified MI data series (MI-modified) matches well all overlapping INE series except the period 1956–1958. It also matches well Carpintero and Naredo (2006) series starting in 1960, which in turn matches FAOSTAT data starting in 1970. Therefore, we used INE (1960) data from 1939 to 1945, the modified MI data series from 1945 to 1959, Carpintero and Naredo (2006) data from 1960 to 1969, FAOSTAT (FAO 2016) data from 1970 to 1989, and IDAE (2015) for 1990–2013.

Graph 3.17a shows the disparity between different published statistics of electricity consumption in Spanish agriculture during the mid-twentieth century, which is solved by our corrected estimation of MI data. Graph 3.17b shows our estimation of

Graph 3.17 Historical evolution of on-farm electricity use in Spanish agriculture according to various sources, 1939–1976 (a) y 1898–2014 (b), in petajoules/year

annual electricity consumption from 1898 to 2013. The estimated direct electricity consumption in agriculture grew 10-fold in two decades, from 7 TJ at the beginning of the twentieth century to 70 TJ in 1922. By 1955, it had grown ten-fold again, at 656 TJ, and again in 1980, at 7646 TJ. It peaked in 2007 at 20,279 TJ and dropped down to 13,924 in 2013, to grow again to 18.6 PJ in 2016.

We have also estimated off-farm (“upstream”) electricity consumption for agriculture in our selected time steps (Graph 3.18b and c). This electricity is used for obtaining unconventional water sources, including desalination and water pumping in channels and diversions. We multiplied the quantity of water coming from these sources calculated in Sect. 3.1 by energy consumption coefficients from Corominas (2010), of 1.2, 3.7 and 0.25 KWh/m³ for diversions, desalination and reuse, respectively. The results are shown in Graph 3.18a.

The electricity employed to obtain irrigation water from unconventional sources (Graph 3.18a) rose from 1092 TJ after the construction of Tajo-Segura diversion in 1979, to 3716 TJ in 2008 when other diversions and many desalination plants were operating. Irrigation electricity grew from 7 TJ in 1900 to 223 TJ in 1933, 473 TJ in 1950 and 23,099 TJ in 2008. A large share of the growth in the last decades has been due to the rise in off-farm electricity use.

Overall, direct energy consumption in irrigation in Spain grew from 8 TJ in 1900 to 31,091 TJ in 2008. Despite most energy consumption was electricity at the beginning of the twentieth century, oil fuels consumption rapidly expanded since 1933, and dominated the use of energy in irrigation during the middle decades of the century. Fuel consumption, however, peaked in 1980, while electricity continued growing until the end of the studied period, in line with the growth in electric engines numbers and installed power. In addition, off-farm electricity consumption was also boosted in the last decades, with the expansion of technologies such as desalination and diversion channels.

3.4 Fertilizers

We have reconstructed the consumption of mineral fertilizers in Spain in terms of nutrients on an annual basis, including synthetic fertilizers, saltpeter, and guano. This estimation is based on historical data expressed in total fertilizers amount for the period 1900–1940 and expressed as nutrients during the 1945–2010 period. The first period up to 1940 is composed mainly by statistical data for all types of fertilizers in some single years (namely 1907, 1908, 1919, 1920, 1928, 1930–1935, 1939 and 1940) and a continuous data series of the apparent consumption of total fertilizers from 1898 to 1940 (excluding the 1936–1938 Civil War period). In addition, we have continuous series of ammonium sulphate and sodium nitrate consumption from 1900 to 1914. Our main data source is the work by Gallego (1986), who compiled and systematized historical statistics of fertilizers consumption in Spain during the first half of the twentieth century, including data from Alonso de Illera for 1907 and 1908, data from Junta Consultiva Agronómica government agency from 1919 and 1920,

Graph 3.18 Direct energy consumption for irrigation in Spanish agriculture including upstream electricity consumption from unconventional water sources 1980–2008 (a), total electricity consumption 1900–2008 (b) and total direct energy use 1900–2008 (c), in petajoules/year

and from the *Anuario de Estadística Agraria* reports from 1928 to 1940. In addition, he compiled the foreign trade fertilizer data from the nineteenth century up to the Spanish Civil War (1936). These statistics include information of different items with various levels of aggregation, but the only item that could be studied separately during the whole series is ammonium sulphate. In addition, Mateu (2013) reconstructed sodium nitrate (saltpeter) imports (which can be equaled to apparent consumption) from 1901 to 1914. Therefore, the missing gaps of individual types of fertilizers up to 1914 were estimated using total apparent consumption of fertilizers in the given year, minus ammonium sulphate and sodium nitrate, multiplied by the average of the share of each individual type of fertilizer in the closest years where data is available. For example, superphosphate consumption in 1912 was estimated subtracting ammonium sulphate and sodium nitrate consumption to total fertilizer apparent consumption in 1912 and multiplying the result by the average of the percentage represented by superphosphate in total fertilizer consumption minus ammonium sulphate and sodium nitrate in 1907, 1908, 1919 and 1920. Potassium sulphate and potassium chloride consumption values in 1920 were much higher than the values of close years, so we considered them outliers and assumed that production was the same as in 1919.

Data for the 1941–1944 period was estimated by exponential interpolation using 1940 and 1945 data. Data from 1945 onwards were taken directly from the selected Spanish government official statistics (*Anuario de Estadística Agraria* reports, MAIC 1928, 1930, 1931; MA 1933, 1934, 1935, 1939, 1940, 1973; MAPA 1990, 1999; MARM 2010; MAGRAMA 2013a, b, c). We only altered this official series in 1957–1964, when we added potassium sulphate data gathered from a National Statistics Institute publication (INE 1965).

As we mentioned above, the data up to 1940 is expressed as gross tons of fertilizers. Therefore, we calculated nutrients using coefficients (Table 3.2). Most of the coefficients were taken from Aguilera et al. (2015). In the cases where no data, or ranges instead of single values, were provided in Aguilera et al. (2015), we took the values from Gallego (1986). We also took fertilizers mixtures nutrient contents from Gallego (1986), who estimated them as the average of nutrients contents. Moreover, we estimated guano nutrient contents based on Wikipedia (2015) and Smil (2001), taking into account that guano nitrogen content in the twentieth century should be in the lower side of its historical range, as richer sources had already been depleted (Table 3.2).

Graph 3.19a shows the evolution of the amounts of nitrogen consumed. We can observe an upward trend during the pre-Civil War period (1898–1935, Graph 3.19a), when consumption grew 26-fold. This growth was only briefly interrupted in 1918 by the effect of the First World War. The dominant N fertilizer during this period was ammonium sulphate, which was obtained mainly through recovery from coke oven gases. Imported Chilean nitrate (and lately also calcium nitrate) also played a role in the supply of mineral N in Spain, while guano was already almost exhausted by the beginning of the century.

Table 3.2 Nutrient contents of fertilizers employed in Spain, percentage of nutrient

	N (%)	P ₂ O ₅ (%)	K ₂ O	Source
Ammonia	82.0	0.0	0.0	Aguilera et al. (2015)
Ammonium Nitrate	35.0	0.0	0.0	Aguilera et al. (2015)
Ammonium Sulfate	21.0	0.0	0.0	Aguilera et al. (2015)
Calcium-Ammonium Nitrate	25.0	0.0	0.0	Aguilera et al. (2015)
Calcium Nitrate	16.0	0.0	0.0	Aguilera et al. (2015)
Urea	46.0	0.0	0.0	Aguilera et al. (2015)
Potassium Nitrate	13.5	0.0	45.0	Gallego (1986)
Complex NPK fertilizers	15.0	15.0	15.0	Aguilera et al. (2015)
Mono Ammonium Phosphate	11.0	52.0	0.0	Aguilera et al. (2015)
Di Ammonium Phosphate	18.0	46.0	0.0	Aguilera et al. (2015)
Ammonium phosphate*	14.5	49.0	0.0	Aguilera et al. (2015)
Phosphate rock	0.0	32.0	0.0	Aguilera et al. (2015)
Triple Superphosphate	0.0	48.0	0.0	Aguilera et al. (2015)
Single superphosphate	0.0	18.0	0.0	Gallego (1986)
Slag	0.0	16.7	0.0	Gallego (1986)
Complex PK fertiizers	0.0	22.0	22.0	Aguilera et al. (2015)
Muriate of potash (potassium chloride)	0.0	0.0	60.0	Aguilera et al. (2015)
Sulfate of potash	0.0	0.0	50.0	Aguilera et al. (2015), INE (1965)
Sodiumnitrate	15.0	0.0	0.0	Smil (2001)
Mixtures	Dynamic coefficient			Gallego (1986)
Cianamida de cal	20.0	0.0	0.0	Smil (2001)
Kainita	0.0	0.0	18.0	Gallego (1986)
Silvinita	0.0	0.0	18.0	Gallego (1986)
Guano	10.0	10.0	2.5	Wikipedia (2015), Smil (2001)

The post-Civil War period (Graph 3.19b) started with stagnant use of N fertilizers, which only surpassed pre-war levels by the mid-1950s. This stage corresponds to the Autarky period of Franco's dictatorship and was followed by an exponential growth up to 1979. Growth slowed down onwards, with significant variability between years, but still continued up to 2000, when N fertilizer consumption peaked at 1279 Gg N. After that year, N fertilizer consumption fell to a minimum of 740 Gg N in 2008, and partially recovered afterwards, reaching 962 Gg N in 2013. The N fertilizer mix was dominated by ammonium sulphate until the late-1960s, when it was surpassed by calcium-ammonium nitrate. Urea and complex fertilizers became major N sources in the 1970s and now represent the majority of the N fertilizer mix, together with calcium-ammonium nitrate.

Graph 3.19 Nitrogen fertilizer consumption in Spain, 1898–1935 (a) and 1900–2013 (b), in Gg N/year

Phosphate fertilizer consumption (Graph 3.20a) show a similar pattern than N fertilizer consumption. Phosphate consumption grows by one order of magnitude during the first third of the twentieth century (Graph 3.20b). The relative growth is not as high as for N, but initial levels of P consumption are higher. The drop in 1918 is also very evident in this case. Phosphate fertilizer consumption is completely dominated by single superphosphate during this period, with minor amounts of rock phosphate, Thomas meal, mixtures and other (Graph 3.21).

Potassium fertilizer consumption trends resemble those of the other nutrients. Growth rates were significant during pre-Civil War period and slowed down during the 1940s and 1950s. Potassium chloride, followed by potassium sulphate, was the major K fertilizers until the mid-1960s. Then, the arrival of compound NPK fertilizers meant a boost in potassium fertilizer consumption growth. After slowing down in the 1970s due to a decrease in the use of potassium chloride, total potassium consumption grew fast again in the 1980s and 1990s, peaking in 1998 at 356 Mg K₂O.

Graph 3.20 Phosphate fertilizer consumption in Spain, 1898–1935 (a) and 1939–2013 (b), in Gg P_2O_5 /year

3.5 Crop Protection

3.5.1 Pesticides

There is very limited information on the amounts of pesticides employed in Spain during the studied period. The available statistics are fragmentary both temporally and in terms of a full accounting of pesticide products. Moreover, only recently they have been expressed as active matter weight. The first available data, from the *Anuario de Estadística Agraria* (MA 1930, 1931, 1933, 1934, 1935, 1939, 1940) reported sulphur, copper sulphate and iron sulphate. An annual series expressed as monetary value of main pesticide categories (including insecticides and acaricides, fumigants, nematicides, fungicides, herbicides, veterinary products, and other) and covering the 1950–1967 period is reported by the 1973 *Anuario de Estadística Agraria* report (MA

Graph 3.21 Potassium fertilizer consumption in Spain, 1898–1935 (a) and 1939–2013 (b), in Gg K₂O /year

1973), and this series is extended up to 1993 by the 1994 edition of that report (MAPA 1994). In 1955, starts another series including the quantities of pesticide products grouped by active matter (including DDT, lindane, malathion, nitro compounds, arsenic compounds, cyanuric compounds, and many other) but reported as total weight, not active matter weight. This series finishes in 1968 and is published in three reports (INE 1960, 1965, 1970). Last, the available data in FAOSTAT (FAO 2016) starts in 1990, groups pesticides by main categories (including insecticides, fungicides herbicides and other and it is expressed as active matter weight.

We estimated the trends in the use of pesticides (sulfur and copper pesticides) from 1900 to 1920 taking the 1933 value as a reference and assuming that the rate of change was similar to that of total synthetic fertilizers during each interval (see Fertilizers section). In 1933 and 1940 we took the reported values of the official statistics, assuming that only sulfur and copper pesticides were used. There is very high uncertainty in the estimation of pesticide use from 1940 to 1990. The conversion of the monetary value series to physical units is hindered by the lack of information of pesticide prices. On the other hand, the conversion of the total weight series to active matter weight requires to know the average richness of each type of pesticide. If we

estimate pesticide use based on 1990 inflation-adjusted (inflation data from Carreras de Odriozola and Tafunell Sambola 2006) monetary value series we get much lower pesticide consumption values than using the total weight series taking Naredo and Campos (1980) approach of assuming 40% active matter weight (Graph 3.22a). In fact, this assumption is really uncertain, as active matter content of commercial pesticides can vary from less than 1% to almost 100%, with very large variations between different commercial products even within a single active matter compound. Moreover, this series shows a sudden drop in the late 1960s that is not supported by the historical sources, and if we examine the trends of the specific compounds, we

Graph 3.22 Historical evolution of synthetic pesticide use in Spain (excluding sulfur and copper pesticides), according to different estimations, 1950–2011, Gg Active matter /year. Price-based series is calculated from MA (1973) and MAPA (1994); total amount-based series is calculated from INE (1960, 1965, 1970), assuming 40% average active matter; active matter series is from FAOSTAT (FAO 2016)

Graph 3.23 Historical evolution of pesticide use in Spain, 1900–2008, Gg /year

find very unrealistic oscillations that suggest that those statistics are not very accurate (Graph 3.22b). Therefore, we have selected the estimation based on prices instead of that based on total weight.

The selected series in Graph 3.22a suggests that most growth in synthetic pesticide use took place during the 1970s and 1980s decades, being more or less stagnant afterwards. Graph 3.22b shows the erratic behavior of individual pesticides use during the 1955–1968 period according to INE. This lack of consistency has led us to discard this data source (Graph 3.23).

Our reconstruction of pesticide use during the twentieth and early twenty-first centuries shows two major growth periods, one during the first third of the century, with the growth in copper and sulfur pesticides, and another one after the autarky period of Franco's dictatorship, with the growth in synthetic pesticide use. However, the copper and Sulphur series is only based on published statistics during the 1933–1970 period. Therefore, there is a high uncertainty in this series before and after that period.

3.5.2 Greenhouses

Greenhouses, tunnels, and plastic mulches now represent an important share of horticultural crop production in Spain. The first published data on greenhouse and protected crop areas in Spain is in the 1975 *Anuario de Estadística Agraria* report (MA 1975a, b). Thereafter, the official statistics offer data on some of these items in 1981 (MAPA 1981), and on all of them in 1984 and 1986 (MAPA 1984, 1986). We estimated area values in the middle years of those periods, and in years previous to 1975, assuming constant growth rates. After 1986, protected crops data were published on an annual basis. In some of these years, we have data from the previous year or years. We selected preferably the latest published data, which sometimes had mod-

Graph 3.24 Historical evolution of greenhouses, tunnels and mulches surface areas in Spain, 1970–2012, in thousands of hectares

ifications of previous reports (MAPA 1988, 1989, 1990, 1992, 1993, 1997, 1999, 2001, 2002, 2004, 2006, MARM 2008, 2010, MAGRAMA 2012, 2013a, b, c). The complete series is shown in Graph 3.24a while Graph 3.24b shows 5-year average data in our selected time steps. According to an official 2008 survey, about 97% of fixed installations are plastic-covered and 3% glass-covered (MARM 2008a, b, c).

The reported surface areas in 1975 were 310 ha of fixed installation, 45 ha of tunnels and 120 ha of plastic mulches. Maximum surface area of fixed greenhouse installations was reached in 2006, with 52,867 ha, and in 2012 it had dropped to 48,206 ha. Maximum surface area of tunnels was reached in 2006, with 14,621 ha, and maximum area of plastic mulches was reached in 2002, with 116,172 ha. The latter dropped heavily in the following years, down to 44,827 ha in 2012.

Thus, the growth in this input was one of the latest among the agricultural inputs employed in Spanish agriculture. It was only possible when the technologies used in the construction of plastic-covered greenhouses and other crop protection techniques used in Spain were mature enough to be economically applied at the large scale. Moreover, greenhouse crop production is largely devoted to off-season and fresh produce for export, which are dependent on well-developed distribution chains that were only present in Spain relatively late.

3.6 Use of Inputs in the Agricultural Sector (Imports)

In the previous sections, we saw how the growth of external inputs was unstoppable, especially since 1960, making it possible to intensify and specialize production as described in the previous chapter. Table 3.3 shows all the inputs used from 1900 to 2008, distinguishing between industrial and biological inputs, as well as their different behavior throughout the period. The use of inputs generally increased by two

Table 3.3 External inputs used by Spanish agriculture (TJ), 1900–2008

	1900	1930	1950	1970	1990	2008
Feed	1269.9	2046.8	1119.7	53,402.6	51,822.0	187,841.6
Seeds	314.6	183.6	578.2	0.0	0.0	5335.6
Total non-industrial inputs	1584.5	2230.4	1697.9	53,402.6	51,822.0	193,177.0
Traction	528.9	2131.5	5681.3	81,695.6	103,296.4	129,665.6
Irrigation	995.3	2132.2	5096.0	20,712.0	58,565.5	75,406.9
Chemical fertilizers	1884.1	17,865.7	15,142.6	75,240.8	104,987.8	77,618.1
Crop protection	25.8	794.9	653.5	2384.8	24,369.3	31,135.1
Total industrial inputs	3432.2	22,924.2	26,573.5	180,033.3	291,219.0	313,825.7
Total external inputs	5018.7	25,154.6	28,271.3	233,436.0	343,041.0	507,002.7
1900 = 100						
Feed	100	161	88	4205	4081	14792
Seeds	100	58	184	0	0	1696
Total non-industrial inputs	100	141	107	3370	3271	12192
Traction	100	403	1074	15,446	19,530	24,516
Irrigation	100	214	512	2081	5884	7576
Chemical fertilizers	100	948	804	3003	5572	4120
Crop protection	100	3081	2533	9243	94,455	120,679
Total industrial inputs	100	668	774	5245	8485	9144
Total external inputs	100	501	653	4651	6835	10102

Source Author's own compilation based on statistical sources and the use of coefficients included in Aguilera et al. (2015)

orders of magnitude in the period between those two years, two thirds of which were industrial inputs. Industrial inputs and their energy costs grew strongly in the second half of the 20th century, first with the use of chemical fertilizers and mechanization, then by irrigation and crop protection. As a result, yields per unit area increased, especially in irrigated areas and in farms using new seed varieties, both hybrid and improved. In fact, the use of seeds particularly increased between 1980 and 2008 with the arrival of industrial germplasm from specialized global companies. The most immediate effect of the application of this land-saving technology was the use of varieties that were more productive than traditional ones under optimum nutrient and moisture supply conditions. But that was not the only effect. It also broke the necessary rotations of traditional management to adapt to the shortage of both nutrients and moisture. Thus, there was an expansion of monocultures and crop rotations determined not by agronomic rationality but by agricultural market demands. Resulting biodiversity reductions favored the appearance of plant plagues and diseases and additional use of phytosanitary products that had until then been quite limited. These kinds of chemical remedies generated a vicious circle in which

the breaking of trophic chains (the use of insecticides led to the disappearance of beneficial insects that control insect plagues), along with the progression of crops and homogeneous varieties over large stretches of land, made it necessary to increasingly use these substances to control pests and diseases. This item visibly grew the most over time, despite not exceeding 6% of total energy expenditure in 2008.

In the next chapter, we will see the effects of mechanization on human work, including the elimination of animal labor. The use of mechanical traction became widespread between the sixties and seventies and never stopped growing, even in the midst of the economic-financial crisis. Irrigation followed a similar course: at first, irrigation was linked to large hydraulic works and later to so-called “irrigation modernization”, consisting in the ever-increasing role of groundwater elevation and pressurized irrigation networks requiring a high energy use. To finish, we have to mention that coinciding with the livestock production process described above, feed grew spectacularly, multiplying by a factor of 121 since 1900. In 2008, it accounted for 38% of the energy value of all inputs used in the agricultural sector. This phenomenal growth of inputs generally explains Spanish agriculture’s loss of efficiency, as we will see in Chap. 5. Graph 3.25 clearly shows the enormous amount of energy originating from outside the agricultural sector that was necessary to inject into agroecosystems to maintain the continuous growth of agricultural production. While biomass DE grew by 38%, the use of external energy multiplied by a hundred. In 1900, industrial inputs from outside the agroecosystem and used for production represented only 14.5% of total invested energy; in 2008, that percentage had risen to 62%, and if we add the feed from Latin America, it reached 99.4% of total energy invested in agricultural production; that is, practically all the energy invested came from outside the agricultural sector. The socio-economic consequences of this are described in the following chapter.

Graph 3.25 Energy value of the inputs used in Spanish agriculture, in TJ. *Source* see Table 3.3

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